DESIGN FOR DISASSEMBLY

AN IMPLEMENTATION OF C2CAD FRAMEWORK

By

RACHEL RUMSEY

Bachelor of Science in Design, Housing and

Merchandising

Oklahoma State University

Stillwater, Oklahoma

2008

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2009

DESIGN FOR DISASSEMBLY

AN IMPLEMENTATION OF C2CAD FRAMEWORK

Thesis Approved:

Dr. Cheryl Farr

Committee Chair and Thesis Advisor

Dr. Donna Branson

Committee Member

Dr. Randall Russ

Committee Member

Dr. A. Gordon Emslie

Dean of the Graduate College

ACKNOWLEDGMENTS

I would like to take this opportunity to thank the many people who helped me toward the success of my thesis. Thank you to Dr. Cao who encouraged me in my effort to learn about sustainability and guided me through the process of submitting and securing a grant through the EPA P3 competition. His expertise and passion for solving the world's problems inspires me. Part of this thesis was funded by the U.S. Environmental Protection Agency under a STAR Research Assistance Agreement No. SU83351701 (P3 Award: A National Student Design Competition for Sustainability Focusing on People, Prosperity, and the Planet).

I would like to thank my advisor and committee chair, Dr. Cheryl Farr who helped me transition research into written form and complete this thesis. I would like to thank my committee member Dr. Randall Russ in helping me complete the thesis process. I would like to thank my committee member Dr. Donna Branson and for her contribution to my thesis. The committees' expertise and experience contributed to the excellent opportunities and learning experiences I had at Oklahoma State University. Thank you to the ever helpful departmental faculty and staff during my experience at Oklahoma State University. I would like to thank my family for their support in completing my goals. Finally I would like to thank my best friend, and loving husband, Matthew. His support and encouragement has made my accomplishments and make my future aspirations possible.

TABLE OF CONTENTS

Chapter Page

I. I. INTRODUCTION 1

Statement of the Problem 1
Purpose and Objectives 3
Definitions 4

II. REVIEW OF LITERATURE 6

Background 6
Cradle to Cradle Concept 7
Cradle to Cradle Design Process 7
Development of the Cradle to Cradle Apparel Design (C2CAD) Model 9
Design for Disassembly Application in Research and Industry 9
Sustainability 11
The Apparel Industry's Impacts on the Environment 12
Cradle to Cradle Disassembleable Apparel Design and Production 16
Summary 17

III. METHODOLOGY 18

Summary of Creative Process Plan 18
Production 19
Materials 19
Outcome 20

Chapter Page

IV. MANUSCRIPT....21

Abstract....22
Introduction....23
The Apparel Industry's Impacts on the Environment....23
Cradle to Cradle Concept....24
Cradle to Cradle Disassembleable Apparel Design and Production....25
Purpose and Objectives....27
Inspiration....28
Material Selection and Testing....28
Outer Shell Fabric Selection....29
Lining Fabric Selection....31
Thread Selection....31
Methods of Disassembly....32
Design Development....34
Design Evaluation....35
Discussion, Conclusions, and Recommendations....36
References Cited....46

V. CONCLUSION....48

REFERENCES CITED....50

APPENDICES....53

LIST OF TABLES

Table Page

1. Test Protocol Summary..38

2. Dying Process for Worsted Wool 38

3. MSDS Assessment of Huntsman Lanasol Dyes used for Dye Assessment ...38

4. Crocking Test for Wools...39

5. Laundry Test for Wools 39

6. Strength Test for Wools 40

7. Sunlight Test for Wools 40

8. Pilling Test for Wools...40

9. Costing Estimate 41

LIST OF FIGURES

Figure Page

Manuscript Figures

1. Photograph of Dye Color 42

2. Photographs of Garment Details 43

3. Jacket Shell 44

4. Jacket with x-ray view of interior components 45

Appendix Figures

1. Herman Miller Mirra Chair...54

1.2. Herman Miller Celle Chair 54

2. Material Assessment Protocol..55

3. C2C Conceptual Framework for Apparel Design and Production 56

4. EPA P3 Honorable Mention Certificate 57

CHAPTER I

INTRODUCTION

A projected 10,812,760,000 pounds of cotton will be consumed by Americans in 2010 based upon estimated population and average cotton consumption of 35 pounds per person per year (U.S. Census Bureau, 2004; National Cotton Council of America, 2005). This number fails to include all of the non-cotton apparel products consumed yearly. For the projected cotton production in 2010, an estimated 10,812,760,000 pounds of harmful additives, such as pesticides, will be used on the plants and soil as they are grown as a result of one pound of additives used per pound of cotton (National Cotton Council of America, 2005). Wool is another fiber widely used in apparel products. In 2006-2007 35,897,435 pounds of greasy wool (meaning it will lose 30-70% of its weight after cleaning) were produced in the U.S. (ASI, 2007, Kadolph, 2007). The apparel industry's solid waste is currently four million tons per year (Council for Textile Recycling, 1998). The three million pounds of used clothing donated each year to charitable organizations are also landfill bound and adding up quickly (Chang, Chen, & Francis, 1999).

Organic, and recycled apparel are gaining attention and this bodes well for the future of responsible design and manufacturing. Current products claiming eco-friendliness may mislead consumers. Consumers see an item that is made from recycled materials or organic fiber and feel better about their purchase (Ho, 2003). Customers' lack of education restricts their ability to judge the true sustainability of an apparel item (McDonough & Braungart, 2002). The product's fiber may be of "organic" origins, but the dyes, fabric treatments, and trim may not have sustainable characteristics. The added components take a seemingly environmentally friendly product and commit it to a landfill (McDonough & Braungart, 2002). Based on observation apparel products may promote organic fiber and ignore the other attributes.

Every product has a lifecycle, often a "cradle-to-grave" cycle, meaning the product is manufactured, purchased, used and thrown into a landfill, or incinerated (McDonough & Braungart, 2002). Although this wasteful cycle has become the norm, the lifecycle of a product need not be so grim. In William McDonough and Michael Braungart's book, *Cradle to Cradle* (C2C), the authors describe a lifecycle based on nature, which utilizes science and natural resources in ways that eliminate negative side-effects from manufacturing, use or disposal of a product (McDonough & Braungart, 2002). The C2C model provides a model that can be used in the elimination of toxins and harmful processes, and creates a closed nutrient loop that eliminates all waste from the lifecycle of a product.

Based on observation of apparel products boasting eco-friendliness it appears that important steps required for eco-effectiveness are skipped. Inappropriate dye choices can lead to color shifting, crocking, and quality problems. Details, such as the type of thread used to sew the garment, can take an otherwise eco-effective garment and ruin the potential to recycle. The introduction of an incompatible element such as thread is considered "toxic" if it is unable to be recycled with the rest of the product. Apparel products often utilize incompatible or toxic adhesives and interfacings to create the desired support or structure of the design. If an incompatible zipper, button, snap, or even the paint or lacquer on a closure is used, the product is landfill bound. The apparel industry would benefit from having a model and example of apparel that is truly eco-effective and sustainable.

In previous research, Gam (2007) adapted McDonough and Braungart's C2C concept and material assessment model into an appropriate format for the apparel industry. The model incorporates steps the apparel industry is familiar with into a model with C2C theory. The resulting model was the C2C apparel design (C2CAD) model. Gam's (2007) research provided evidence that a simple product (100% organic cotton knitted sweater) can be executed following the model. This demonstration, however, does not show how a more complex product could be developed using the model. Since most apparel products have multiple components a complex product should be used as a proof-of-concept in order to move C2CAD into mass production within the industry. A men's jacket was chosen to be the subject of a proof-of-concept because of its complexity and usual high "toxicity" due to the number of components that are not compatible with the C2C concept of recycling. If a complex product such as a man's jacket can be produced in a cost effective, sustainable manner in mass production, other apparel products should be feasible.

Purpose and Objectives

The purpose is to develop a prototype disassembleable man's jacket that can be an example of an eco-effective, complex garment that can be compatible with C2C concept of recycling.

The objectives of this research are to: 1) Source and test components for sustainable apparel including, fabric: interfacing, thread, seams, stitches, closures, dyes and design for sustainability. 2) Evaluate and select appropriate components and combinations of components to construct a men's jacket as an example of sustainable disassembleable apparel product. 3) Design and construct a jacket adaptable to mass production. 4) Evaluate the performance, cost, and overall results of the jacket. 5) Revise and reevaluate jacket as needed. 6) Exhibit jacket, related design features, and textile test results.

Definitions

Biological Nutrient: a material or product that can be composted returning nutrients to the earth (McDonough & Braungart, 2002, pg 105).

C2C: Cradle to Cradle: a concept developed by McDonough and Braungart in their book titled Cradle to Cradle discussing the need for change in product design and production and a basic idea on how to enact the changes (McDonough & Braungart, 2002 pg 92-93).

C2CAD: C2C Apparel Design: Applying the C2C concept to Apparel Design Process (Gam, 2007)

C2CDADP: C2C Disassembleable Apparel Design and Production: Term used to refer to the C2C process as applied in apparel design and production in regards to application of design for disassembly

Crocking: AATCC test which is used to determine the amount of color transfer from the fabric and dye that occurs, includes both wet and dry tests (American Association of Textile Chemists and Colorists, 2004, AATCC Technical Manual test method 8-2001)

Cradle to Grave: refers to product manufactured, purchased, used and thrown into a landfill, or incinerated; does not recycle (McDonough & Braungart, 2002, pg27, 93-98).

Design for Disassembly: design products with multiple components to be separated at the end of their useful life into appropriate components for recycling (McDonough & Braungart, 2002, pg 114-115).

Downcycle: the process which uses existing products and turns them into new lower quality products: Term to refer to existing recycling process (McDonough & Braungart, 2002 pg 56-59).

Eco-Friendly: a product or process not as bad as traditional methods, but still harmful (McDonough & Braungart, 2002).

Eco-effectiveness: how friendly the product is to the environment and humans considering the effects of the product or process (Prasad, pg21).

Green: a term used to describe products and processes that are sustainable/friendly to the environment, humans, and animals (Braungart & McDonough, 2002).

Greenwashing: term referring to the misinformation dispersed to the public regarding the eco-friendliness, or sustainability of a product or service (Ho, 2003)

Jacket: refers to a suit jacket; original intention for design for disassembly proof-of-concept

Lifecycle: the production, use and disposal of a product (McDonough & Braungart, 2002).

Organic: describes a product or process which does not use any harmful additives such as pesticides, often used in reference to cotton, and food products, grown or raised without harmful additives (McDonough & Braungart, 2002).

Outerwear Overcoat Type Jacket: a simple man's jacket to be worn over clothes outside as protection from cold and weather; the evolved design based on fabric selection

Recycle: describes the process of using an existing item which no longer is useful and turning it into a new product of the same quality level as the original product (McDonough & Braungart, 2002 pg 56).

Sustainability: processes and products that do not lead toward any economic or quality of life losses (Sutainability Report 2004)

Technical Nutrient: a man-made material or product that can be recycled into a new product of the same quality level as the original (McDonough & Braungart, 2002, pg 109).

Toxic: if an item or product is referred to as toxic then it is unable to be recycled due to harmful aspects such as dye, or mixing of biological and technical nutrients, a poisonous substance, etc. (McDonough & Braungart, 2002).

CHAPTER II

REVIEW OF LITERATURE

This literature review includes information related to the Cradle to Cradle Disassembleable Apparel Design and Production (C2CDADP) processes including those models that form a foundation for C2CDADP. The review excludes application of the sustainable principles to non-apparel products. The review will provide the background for the design, and completion of the first C2CDADP product as a proof-of-concept in the form of a prototype man's jacket

Background

The complexity of design and production problems today influences all aspects of environmental, health, and economic issues. Since the industrial revolution, the apparel industry has played a significant role in the process of product design and production (McDonough & Braungart, 2002). The influence of the apparel industry has and can be used to dramatically alter the effects of manufacturing, for better or worse (McDonough & Braungart, 2002).

As technology changes in the apparel design and production industry, the responsibility of the designer increases in regards to the impact of their product (McDonough & Braungart, 2002). The result of previous generations' manufacturing decisions is directly related to the depletion of limited natural resources (McDonough & Braungart, 2002). This depletion of resources requires changes in product design and production to create products that contribute to sustainability and eliminates potential negative effects (McDonough & Braungart, 2002).

Cradle to Cradle Concept

The Cradle to Cradle (C2C) design concept developed by McDonough and Braungart (2002) is a prominent concept within sustainability. In the book "Cradle to Cradle" McDonough and Braungart focus on sustainable design, products, processes, and application of the process (McDonough & Braungart, 2002). The primary goal of analyzing and preparing for the lifespan of a product (manufacturing, use, and disposal) is ensuring the waste of one product is used as "food/fuel" for another product of equal quality. The use of product waste to provide raw materials for new products and nutrients for the earth has the potential to revolutionize the process of apparel design and production decreasing the number of products ending in landfills (McDonough & Braungart, 2002). Instead of heavily contributing to the world's health and environmental problems, the reduction of problems by the apparel industry will provide a dramatic example for other industries and consumers by redefining what is possible.

Cradle to Cradle Design Process

Every product has a lifecycle, often a "cradle-to-grave" cycle, meaning the product is manufactured, purchased, used and thrown into a landfill, or incinerated. Although this wasteful cycle has become the norm over the last two centuries, the lifecycle of a product need not be so grim. McDonough and Braungart (2002) describe a model based on nature, which utilizes science and natural resources in ways that create no negative side-effects. The C2C model guides the elimination of pollutants and harmful processes, utilizing all resources as nutrients and results in creating a closed nutrient loop. A closed nutrient loop is possible when the “waste/excess” of an item is used as “food/fuel” for a product. Using the “waste/excess” of an item to provide nutrients for another is a simple, yet challenging concept. Within the Cradle-to-Cradle model all nutrients are considered either biological or technical (McDonough & Braungart, 2002).

If the nutrients are biological they can be mixed for optimal characteristics, meaning multiple types of fibers can be used together in a yarn, textile, or product (McDonough & Braungart, 2002). Biological nutrients are substances found in nature and returnable to the earth for soil nutrients to produce other crops, such as fiber, or food without harmful effects through composting (McDonough & Braungart, 2002). At the end of their use, natural fibers are ground up and processed into new fabric or composted and return their nutrients to the ground closing the biological loop (McDonough & Braungart, 2002).

Technical nutrients are synthetic nutrients that must remain separate to ensure a closed lifespan loop. Technical nutrients cannot be mixed with biological nutrients or even different technical nutrients. Technical nutrients are manufactured nutrients able to be recycled into new products of the same quality as the original (McDonough & Braungart, 2002). The recycling process allows the product at the end of its usage to be reused infinitely rather than going to a landfill (McDonough & Braungart, 2002).

Development of the Cradle to Cradle Apparel Design (C2CAD) Model

As sustainability develops the need for a model to use as a guide within the apparel industry became clear. A model based on the Cradle to Cradle theory was Cradle to Cradle Apparel Design (C2CAD)and incorporating the Material Assessment Protocol (Appendix 2) developed by Gam (2007) emphasizing functional, aesthetic, and sustainability for the apparel industry. It has not been implemented in the industry; the model was tested by Gam (2007). Gam's (2007) proof-of-concept used organic cotton children's knitwear product and sustainable dyes.

Design for Disassembly Application in Research and Industry

The recent trends in organic cotton, and recycled apparel are gaining attention and the response is favorable. Environmentally responsible design and production is making products that claim to meet some sustainability standard and have a higher appeal to consumers than non-environmentally responsible products (Ho, 2003). When the average consumer sees that an item is made from recycled materials or organic fiber, the customer then feels better about their purchase, and themselves (Ho, 2003). Lack of information limits the consumers' ability to judge the true eco-effectiveness of an apparel item. Products being deliberately represented as environmentally responsible without any information to support the claim are called greenwashed (Ho, 2003). Greenwashing intends for consumers to think they are making environmentally responsible purchases while the product fails to live up to sustainable expectations (Ho, 2003).

A product's fiber may be of "organic" origins, but the dyes, fabric treatments, trim, and closures may fail to be sustainable (McDonough & Braungart, 2002). The mixing of biological and technical nutrients, toxic components and finishes destroy the product's sustainability. Upon examination current apparel products touting eco-friendliness appear to skip integral steps in the design process that are required for eco-effectiveness. Many products claim environmental responsibility without the information to back it up (Ho, 2003). Inappropriate dye usage can lower the quality of the eco-friendly product, leading to problems such as color shifting, and crocking (Kadolph, 2007). Details such as the type of thread used to sew the garment can take an otherwise eco-effective garment and ruin its ability to recycle (McDonough & Braungart, 2002). The closures used on apparel products can easily destroy the sustainability of a garment. Apparel products often utilize adhesive and interfacings to create the desired support, or structure of the design. These underlying components contain many problematic chemicals. The need for development in sustainable components is necessary in order allow for truly sustainable apparel to exist in the marketplace. Some sustainable options are commercially available for interior products although apparel products have limited options. Two examples of environmentally conscious fabric are Tematex by True Textiles, and Climatex Lifecycle (Climatex, 1997; True Textiles).

The Herman Miller Company produces the Mirra Chair that disassembles in less than fifteen minutes into single types of components (Herman Miller, 2003). The chair is not perfect because 4% is not able to be recycled, however, it is a good start with 96% recyclable (Appendix 1). In the disassembly process the chair breaks down into parts that can continue in their lifecycle as recyclable, or compostable.

The Celle Chair (Appendix 1.2) by Herman Miller provided the next step in design for disassembly in chairs (Herman Miller, 2006). The Celle is 99% recyclable and reduces the disassembly time to less than five minutes. The Celle, designed by Jerome Caruso, uses a flexible polymer that responds to the body for support which adjusts with the user. Caruso's chair and technology earned a MBDC Gold Cradle-to-Cradle certification for its achievement in environmentally intelligent design. By utilizing the cradle to cradle guidelines, Herman Miller show innovation and responsiveness to the issue of decreasing the complexity and time of disassembly.

Sustainability

Sustainability is defined by products and processes that do not lead toward economic or quality of life losses for people, prosperity or the planet (McDonough & Braungart, 2002). Sustainable design includes the planning, and execution of the products (McDonough & Braungart, 2002). Apparel design sustainability requires planning, but offers many benefits in all aspects of design and production. Financial benefits, a better product, and long term success are all benefits a company can expect from enacting sustainable practices (McDonough & Braungart, 2002). A portion of ensuring successful products is to meet the target market's expectations in terms of quality, price, and style. The fast-paced environment of apparel design and production is able to meet the consumer's needs if proper research is done, and creativity is used while maintaining the goal of sustainability (McDonough & Braungart, 2002).

One example of incorporating sustainability in apparel design and production is utilizing local environments at manufacturing facilities. Energy can be generated by natural renewable resources to run the manufacturing (McDonough & Braungart, 2002). Wind, water, and solar energy are effective options of generating large amounts of energy. Simple solutions such as proper window placement and insulation from a grass covered roof are some current easy options for buildings (McDonough & Braungart, 2002). These solutions dramatically reduce the cost of manufacturing helping ensure proper price point (McDonough & Braungart, 2002).

The Apparel Industry's Impacts on the Environment

The apparel industry has contributed to substantial environmental damage beginning in the industrial revolution (Atmosphere, Climate & Environment Information Programme). Apparel production creates large amounts of waste by-products, excessive energy use, and overflowing landfills with short term use products that have long term consequences (McDonough & Braungart, 2002). Apparel manufacturing is responsible for more solid waste production than any other industry (Franklin Associates, Ltd). Synthetic textiles are made with valuable limited resources, and create toxic waste, although natural fibers are generally no less harmful (McDonough & Braungart, 2002).

A staggering 20 gallons of water are contaminated in producing a single pound of textile (McDonough & Braungart, 2002). The toxins in the contaminated water are transferred to the water's future users, fish, plants, or even humans (McDonough & Braungart, 2002). The bio-accumulation over time has resulted in the chemicals being commonly found in human blood streams. Bio-accumulation is the buildup of substances in living organism tissue, often referring to harmful chemical accumulation (Dictionary.com, 2008). This contamination of all life-forms cannot be ignored any longer as health and ecological problems compound every year.

Health problems are an unfortunate part of current society. These problems may be related to the chemicals found in human bodies. An average of 91 chemicals found in consumer products and industrial pollution were discovered in the blood and urine of participants in a Mount Sinai School of Medicine Body Burden study (Environmental Working Group, 2003). A total of 167 types of chemicals were found in the participants, 76 of which are known to cause cancer, 94 are considered toxic, and 79 that cause birth defects (Environmental Working Group, 2003). Childhood cancer has increased 26% between 1976 and 1999, and childhood brain cancer increased a 50% (Environmental Working Group, 2003). Autism, a nervous system disorder, is 10 times more prevalent in 2003 than in the 1980's (Environmental Working Group, 2003). These shocking statistics should inspire choosing healthy alternatives in our daily lives so bio-accumulation is no longer a problem as the chemicals diminish, rather than increase over generations. Intelligent sustainable design decisions have the opportunity to impact many generations in a positive way (Sustainability Report, 2004).

Natural fibers, although they may seem environmentally friendly, are regularly contaminated through synthetic fertilizers, pesticides and defoliants. In 2000, cotton had approximately 84 million pounds of pesticides added to the 14.4 million acres of conventional cotton grown in the United States (United States Department of Agriculture, 2004). Of these pesticides seven of fifteen are "known", "likely", "possible", or "probable" human carcinogens as of 2000 (United States Environmental Protection Agency, 2006). One pound of additives is used in order to produce one pound of cotton (National Cotton Council of America, 2005). The quantity of harmful additives in conjunction with the average 35 pounds of Cotton consumed per capita by U.S.

consumers' results in an astounding amount of chemicals used (National Cotton Council of America, 2005). According to the projection of the national census of 2000 for 2010 the population of the United States will be 308,936,000 (U.S. Census Bureau, 2004). This projected population figure combined with the average cotton consumed per person per year equals 10,812,760,000 pounds of cotton estimated to be consumed in 2010. An equal amount of 10,812,760,000 pounds of chemical additives, such as pesticides and defoliants will be used on cotton in 2010 as well if the population projections are accurate.

The cotton's contamination resulting from such chemical application results in devastating consequences such as a loss of the ability to return to the earth as nutrients (McDonough & Braungart, 2002). Without harmful additives natural fibers, such as cotton, flax, bamboo and ramie, are eco-effective crops and products. Pesticide and defoliant applications to the crops destroy their potential to return to the earth as nutrients through composting. The rapid natural fiber consumption and the accompanying additives during growth lead to huge amounts of contaminated fiber, soil and water (McDonough & Braungart, 2002).

In 2000, 14,000 pounds of insecticides were applied to sheep in the U.S. (OTA, 2008). Even though the U.S. produces a large amount of wool, it is only produces 0.9%, and uses 0.7% of the world's wool (Kadolph, 2007). About 78% of the wool produced in the U.S. is shipped to China (ASI, 2007). Wool comes in many different types from different breeds of sheep but is categorized into lamb's (cut from lambs less than seven months old) Virgin (never processed before made into product) Wool (new or fibers reclaimed from new scraps and thread) and recycled (scraps are shredded back into fibrous state and respun) (Kadolph, 2007). The label wool refers to the fibers past use not as a quality statement (Kadolph, 2007). Recycled wool still performs well as a fabric even though the fibers may be weaker then virgin fibers due to processing (Kadolph, 2007).

Although wool is a natural fiber it has a significant environmental impact. Sheep graze so closely that soil erosion often occurs. While waste is used as fertilizer if there is excess it can run off into water sources. Water and energy use cleaning greasy wool into usable fibers is excessive (Kadolph, 2007). While some wool products can be hand washed but most are dry cleaned (Kadolph, 2007). Dry cleaning solutions have been identified as possible carcinogens, making dry cleaning a hazardous process (Kadolph, 2007). Chemicals, such as synthetic pyrethroid and organophosphates, enter rivers from wool processing and sheep dipping (Pesticides, 2000). Both synthetic pyrethroid and organophosphate are toxic to aquatic life are commonly used in the production of wool (Pesticides, 2000). The top three chemicals used in wool production are considered slightly acutely toxic to humans (OTA, 2008). They are also considered suspected endocrine disruptors and are moderately to highly toxic to aquatic life (OTA, 2008).

When non-hazardous materials and processes are used, all aspects of the product's lifecycle are improved (McDonough & Braungart, 2002). Health effects on employees during manufacturing are reduced or eliminated so there is no need for regulations or cumbersome protective gear (McDonough & Braungart, 2002). The resulting negative effects on the local community are no longer an issue as the water, air, and soil are no longer contaminated. The products' lose potential to transmit toxic substances through dermal absorption into the wearer (McDonough & Braungart, 2002).

Cradle to Cradle Disassembleable Apparel Design and Production

Some companies are utilizing eco-friendly fibers and occasionally dyes but there are no examples of sustainable apparel designed for disassembly. This research will focus on ideas, options, and opportunities for utilizing and demonstrating C2C disassembleable apparel design and production (C2CDADP). The apparel industry accepts designing for disassembly as unrealistic a demonstration of C2CDADP will help to correct the misconception with a proof-of-concept garment.

In order to accurately evaluate the information gained through this review of literature, models will be utilized. The material assessment protocol flow chart (figure 3) will help in maintaining the framework of assessing the materials eco-effectiveness. The C2CAD Model (figure 4) will aid in the design and assessment of the apparel and its components. This comprehensive model although currently unused in the apparel industry will prove to be a valuable tool for C2CDADP.

Four and a half million tons of clothing and footwear are produced in the US annually, and only 1.25 million of those tons are recovered for next use (Environmental Protection Agency manual 530R97002). The recovered products are then used in producing low quality products that ultimately end up in the landfill. In recovering and recycling products the mixture of natural and manufactured fibers, permanent attachments, adhesives and stitching leave most products unable to be recycled. They can only be down-cycled into a lower quality product which still will end up in a landfill (McDonough & Braungart, 2002).

In order for any company to succeed it must make a profit; and, companies producing sustainable products are no exception. The importance of aesthetics, fit, and price in any product is paramount in making a profit. Characteristics such as aesthetics, fit, and function will determine if a garment is purchased, eco-effective garments are no exception. Eco-effective apparel can provide an additional aspect of pleasure in owning a garment that non-eco-effective apparel cannot provide, but must still fulfill the desired aspects of the garment.

Long-term profit is important to consider as a benefit of adopting C2CDADP. Long term prosperity may not influence individuals to purchase a sustainable product over another, but may affect the overall acceptance and support the product and company receive from the community on a long term basis (McDonough & Braungart, 2002). With a lack of waste and harmful air pollution the communities will save money in pollution treatment and prevention, and health implications. The gain is both economical and ecological.

Summary

The importance of incorporating sustainable design into the apparel industry has been discussed showing effects on people, the planet, and prosperity. The initial responsibility of transforming the industry lies with designers as design has been shown to determine at least 80% of the environmental effect of the product's lifecycle (M2 Presswire, 2005). Effects of product choices, components, and production methods can all be dramatically affected by the choices made. The apparel industry is a major influence on production practices and can lead other industries toward better choices.

CHAPTER III

METHODOLOGY

Summary of the Creative Process Plan

The main goal of the research is to create a design for disassembly proof-of-concept. The objectives of this research are to: 1) source and test components for sustainable apparel including, fabric: interfacing, thread, seams, stitches, closures, dyes and design for sustainability; 2) evaluate and select appropriate components and combinations of components to construct a men's jacket as an example of sustainable disassembleable apparel product; 3) design and construct a jacket adaptable to mass production; 4) evaluate the performance, cost, and overall results of the jacket; 5) revise and reevaluate jacket as needed; and 6) exhibit jacket, related design features, and textile test results.

The tasks to accomplish the objectives will include testing components of the design in accordance with AATCC and ASTM standard methods, and experimenting with unique approaches of apparel design and production, and dye and closure options. The target market and design will guide the specifics for the individual project.

Production

Production of the jacket will be made in an effort to emulate mass production methods allowing the proof-of-concept of design for disassembly to make a stronger statement on sustainability. The jacket pattern will be digitized utilizing both Gerber-Suite CAD and an automated cutting table, necessary steps for any apparel product to be produced on a large scale. By using mass production technology for a product the product production feasibility will be determined. Since the feasibility of incorporating design for disassembly into mass production is crucial this integration of technology should help to demonstrate the feasibility of switching over to a new methodology.

Materials

The selection of materials and chemicals is paramount in a sustainable product. All materials will need to meet the criteria to recycle. The shell of the jacket will be a biological nutrient shell. The standard choice of wool for jacket shells will be upheld by using 100% wool. The lining will be a technical nutrient, as is often the case of jacket linings. The thread for the jackets will be biological for the shell, and a technical nutrient thread for sewing the lining. Any dying will be done with sustainable dyes. All these components will be utilized to create the first C2CDADP garment in order to show the feasibility proof of the concept. Materials and chemicals will be tested to ensure appropriate quality levels for the product.

Outcome

The outcome of the project will be a physical example in the form of a man's jacket, and information on how to produce a C2CDADP garment. The results will include testing from related AATCC, and ASTM performance characteristics that are pertinent to the product. The testing that will be included is listed in Table 1.

A new prototype will act as a tool for apparel design and production students to learn the concept and execution of not only the cradle to cradle concept, but of sustainable design, and design for disassembly as well. By incorporating the idea of responsible design choices into the curriculum the concepts will eventually disseminate throughout the apparel industry.

CHAPTER IV

Design for Disassembly: An Implementation of C2CAD Framework

MANUSCRIPT FOR PUBLICATION

AUTHORS:

Rachel Rumsey[a], Huantian Cao[b], Cheryl Farr[a], Donna Branson[a], Randall Russ[a]

[a]*Department of Design, Housing and Merchandising, Oklahoma State University, Stillwater, Oklahoma, USA*

[b]*Department of Fashion and Apparel Studies, University of Delaware, Newark, DE 19716*

The work was funded by The U.S. Environmental Protection Agency under a STAR Research Assistance Agreement No. SU83351701 (P3 Award: A National Student Design Competition for Sustainability Focusing on People, Prosperity, and the Planet).

Design for Disassembly: An Implementation of C2CAD Framework

Abstract

Purpose ─ To develop and demonstrate a disassemblable sustainable apparel product, providing apparel designers and manufacturers a mass production prototype that will provide options to solve problems related to sustainable apparel design and production.

Approach ─ A model developed by Gam (2007) and based on McDonough and Braungart's (2002) "cradle to cradle" model, the C2CAD model utilized in this project to design and produce apparel designed for disassembly.

Findings ─ The development of a prototype apparel product designed for disassembly provides an example of sustainable apparel products that will reduce landfill related outcomes of current apparel products. The complex garments worn on a regular basis have led to the need of design for disassembly. The various components need to be designed in a way that they can be easily separated in order for proper recycling. A men's jacket proof-of-concept prototype was chosen as an example of a complex garment that demonstrates the feasibility of design for disassembly.

Practical implications – Design for disassembly provides practical application for apparel designers and manufacturers. It allows them to address the issue of sustainability through design for disassembly that addresses economic development, and environmental aspects of the product throughout each product's lifecycle.

Originality/Value ─ The apparel product designed for disassembly is demonstrated in this project. The production implements the C2CAD model providing a demonstration of responsible design and production for the apparel industry. If a complex product such as a men's jacket can be produced meeting aesthetic, financial, and sustainable issues in a sustainable manner, industry professionals should have confidence their companies' can produce apparel that is sustainable as defined by cradle to cradle.

Keywords: sustainable, apparel design and production, model, cradle to cradle, disassembly

Introduction

Organic cotton fibers and recycled apparel are gaining attention; this bodes well for the future of environmentally responsible design and manufacturing. Current products claiming eco-friendliness may mislead consumers. Consumers' see an item that is made from recycled materials or organic fiber and feel better about their purchase (Ho, 2003). The product's fiber may be of "organic" origins, but the dyes, fabric treatments, and trim may not have sustainable characteristics. The added components may take a seemingly environmentally friendly product and destine it to a landfill (McDonough & Braungart, 2002).

The Apparel Industry's Impacts on the Environment

The apparel industry has contributed to substantial environmental damage beginning in the industrial revolution (Atmosphere, Climate & Environment Information Programme, 2002). Apparel manufacturing is responsible for more solid waste production than any other industry (Franklin Associates, Ltd, 1993). Synthetic textiles are made with valuable limited resources, and create toxic waste, although natural fibers are generally no less harmful (McDonough & Braungart, 2002).

A staggering 20 gallons of water are contaminated in producing a single pound of textile (McDonough & Braungart, 2002). The toxins in the contaminated water are transferred to the water's future users, fish, plants, or even humans. Bio-accumulation is the buildup of substances in living organism tissue, often referring to harmful chemical accumulation (McDonough & Braungart, 2002). Intelligent sustainable design decisions have the opportunity to impact many generations in a positive way (Sustainability Report, 2004).

Four and a half million tons of clothing and footwear are produced in the U.S. annually, and only 1.25 million of those are recovered for next use (Environmental Protection Agency manual 530R97002). The recovered products are then used in producing low quality products that still ultimately end up in a landfill. In recovering and recycling products the mixture of natural and manufactured fibers, permanent attachments, adhesives and stitching make many products a mix of biological and technical nutrient, and therefore cannot be recycled.

Natural fibers, although they may seem environmentally friendly are regularly contaminated through the use of synthetic fertilizers, pesticides and defoliants. In 2000, cotton had approximately 84 million pounds of pesticides added to the 14.4 million acres of conventional cotton grown in the United States (United States Department of Agriculture, 2004). Of these pesticides seven of fifteen are “known”, “likely”, “possible”, or “probable” human carcinogens as of 2000 (United States Environmental Protection Agency, 2006). Without harmful additives, natural fibers are eco-effective crops and products. When non-hazardous materials and processes are used all aspects of the product’s lifecycle are improved (McDonough & Braungart, 2002).

Cradle to Cradle Concept

In the book, “Cradle to Cradle,” McDonough and Braungart (2002) focus on sustainable design, products, processes, and application of the process. The primary goal of analyzing, and preparing for the lifespan of a product (manufacturing, use, and disposal) is ensuring the waste of one product is used as “food/fuel” for another product of equal quality. The use of product waste to provide raw materials for new products and nutrients for the earth has the potential to revolutionize the process of apparel design and production (McDonough & Braungart, 2002). Instead of contributing to environmental problems the apparel industry has the opportunity to provide a dramatic example for other industries and consumers by redefining what is possible.

Biological nutrients are substances found in nature and are returnable to the earth for soil nutrients without harmful effects through composting (McDonough & Braungart, 2002). Biological nutrients can be mixed for optimal characteristics, meaning multiple types of fibers can be used together in a yarn, textile, or product (McDonough & Braungart, 2002). At the end of a products' use, the biological nutrient can be ground up and repurposed or composted, thereby returning their nutrients to the soil closing the biological loop (McDonough & Braungart, 2002).

Technical nutrients are manufactured substances that are able to be recycled into new products of the same quality as the original (McDonough & Braungart, 2002). Technical nutrients must remain separate and cannot be mixed with biological nutrients or even different technical nutrients to ensure a closed lifespan loop. The recycling process allows the product at the end of its usable life to be reprocessed into a new product infinitely rather than going to a landfill (McDonough & Braungart, 2002).

Cradle to Cradle Disassembleable Apparel Design and Production

Some companies are utilizing eco-friendly fibers and occasionally dyes, but there are no examples of sustainable apparel designed for disassembly. This project focused on ideas, options, and opportunities for utilizing and demonstrating C2C disassembleable apparel design and production (C2CDADP). The development of the C2CDADP helps to correct the misconception of feasibility with a proof-of-concept garment.

The resulting men's jacket from this research utilized a biological nutrient shell, and a quick separating technical nutrient lining to prolong the use of the jacket as well as demonstrate the feasibility of C2CDADP.

Long-term profit is important to consider as a benefit of adopting C2CDADP. Long term prosperity may not influence individuals to purchase a sustainable product over another, but may affect the overall acceptance and support the product and company receive from the community on a long term basis (McDonough & Braungart, 2002). With a lack of waste and harmful air pollution, the communities will save money in pollution treatment and prevention, and health implications (McDonough & Braungart, 2002). The gain is both economical and ecological.

For a product to be profitable it must have consumer acceptance at a price point that will yield a profit. Cotte & Trudel (2008) found that consumers are willing to pay slightly more for an ethical product than others of equal value. Females are more likely to have a stronger environmental attitude (Axelrod, & Fram, 1990). Since women are the primary household shopper, the impact of their purchasing power is substantial (Axelrod, & Fram, 1990). Combining women's' purchasing power with their more environmentally conscious attitude the purchasing potential for sustainable products is widespread.

The initial responsibility of transforming the apparel industry lies with designers. Design has been shown to determine at least 80% of the environmental effect of the product's lifecycle (M2 Presswire, 2005). A model was developed for the apparel industry to guide them through the C2C process (Gam, 2007). The cradle to cradle apparel design (C2CAD) model tested the evaluation protocol using a simple product. The product was 100% organic cotton knitwear that demonstrated the feasibility of the process on a non-complex product. C2CAD's success in the apparel industry hinges upon designers' willingness and ability to create and produce complex products with recycle compatible components. However, most apparel products are complex and have several components that may not be C2C recycle compatible. Thus, design for disassembly becomes a necessity if the compatible components are to be removed. Although some companies are utilizing eco-friendly fibers and dyes, no examples currently of sustainable apparel designed for disassembly were found in the literature.

Purpose and Objectives

Although seemingly eco-friendly products are seen in the apparel market, the sustainability of these items must be seriously questioned. After initial market examination of complex apparel products currently available this designer noted the lack of true eco-effective apparel. The objectives of this research are to: 1) source and test components for sustainable apparel including, fabric: interfacing, thread, seams, stitches, closures, dyes and design for sustainability; 2) evaluate and select appropriate components and combinations of components to construct a men's jacket as an example of a sustainable disassembleable apparel product; 3) design and construct the jacket adaptable to mass production; 4) evaluate the performance, cost, and overall results of the jacket; 5) revise, and reevaluate jacket as needed; and 6) exhibit jacket and related design, research and evaluation information.

The tasks will include testing components of the design in accordance to AATCC and ASTM standard methods, experimenting with unique approaches of apparel design and production, and dye and closure options. The target market and design will guide the specifics for the individual project.

Inspiration

The environmental issues being faced with the apparel industry acted as a catalyst providing a need for solutions. Second, the innovative solution discusses McDonough and Braungart's book "Cradle to Cradle" approach that can be applied to responsible design and production. The third aspect that acted as inspiration for the project was existing innovative products displaying the potential of design for disassembly in product design such as Herman Miller's Mirra and Celle chairs.

Material Selection and Testing

Material selection and testing focused on the first two objectives of the design process. Goals include source and test components for sustainable apparel including, fabric, interfacing, thread, seams, stitches, closures, dyes and design for sustainability. The objectives were initiated simultaneously in order to evaluate and select appropriate components and combinations of components to construct a men's jacket demonstrating the first ever sustainable disassembleable apparel product.

Sourcing and testing components for sustainable apparel proved to be a difficult portion of the process. Sourcing traditional un-sustainable apparel components are easy as a result of the breadth of online vendors for individual designers and the versatility of modern textile mills allows multiple choices.

Outer Shell and Fabric Selection

The shell of the jacket needed to be a biological nutrient in order to maintain the traditional look of men's jackets. The initial goal in sourcing the outer shell fabric was to obtain organic un-dyed wool that was suitable for a man's suit jacket. When vendors willing to sell small quantities of organic un-dyed wool fabric could not be identified the parameters of the fabric search changed to un-dyed wool and C2C certified biological nutrients. Fabric sourcing websites for individuals (denverfabrics.com, fashionfabricsclub.com, etc), websites offering green or sustainable products (nearseanaturals.com, greensage.com, distinctivefabric.com, etc), and websites with vendor information (hktdc.com, etc.) were searched and six swatches were ordered for potential options from two vendors. Acceptable fabric was obtained from TestFabrics Inc. and Pendleton Woolen Mills.

Of the two companies that offered C2C certified fabric (Pendleton and DesignTex) only Pendleton had fabric suitable to work with in an apparel product (Pendleton, 2003, DesignTex, 2006). The thick woolen felt-like fabric was designed for interior products and not ideal for apparel products because it is heavier and stiffer than typical jacket weight fabrics. The fabric was made and dyed with C2C MBDC certified processes meeting both the material assessment and C2CAD model's criteria. The Pendleton fabric was selected in the colors Black and Squash (color name chosen by the company, equivalent to Munsell 2.5YR value of 5 and chroma of 10).

As a result of the selected shell fabric coming pre-dyed another fabric was selected for dying purposes. Un-dyed worsted wool from TestFabrics Inc. was selected although too lightweight to provide the structure a jacket would need without any adhesive interfacings. Since the adhesive interfacings fail to meet the material assessment protocol and the C2CAD model's guidelines the un-dyed worsted wool fabric is used for dying purposes of a fabric designed for apparel use.

The worsted wool was dyed with Lanasol Dye Yellow and Blue (figure 1). The dyes were produced by Huntsman International LLC (The Woodlands, Texas) and recommended by Dr. Tucker Helmes, Executive Director of ETAD North America. Based on the assessment of Material Safety Data Sheets (MSDS) provided by Huntsman (table 2) it was concluded that the two Lanasol dyes chosen have the no known adverse effect on human and environmental health. These two Lanasol dyes were used to dye worsted wool fabric from TestFabrics. The dyes were colorfast without the use of harmful additives. The only addition to the dye was a small amount of salt (ww-1.0 g) to obtain good dye penetration (table 2), and dye selection information (table 3).

Several tests were used in determining the suitability of the fabric choices (table 1). Crocking test results (table 4) were favorable showing good color fastness in dry crocking (P black-4.0, P squash-4.75, ww blue-4.42) and less favorable in wet (P black-3.0 P squash-4.25, ww blue-3.84). The results of the accelerated laundering tests (table 5) indicated the color remained fast to the fabric (4.5-5.0) although some staining occurred from the worsted wool in blue on cotton (ww-2.25) and wool (3.0) , the Pendleton squash stained both nylon (p squash-3.25) and wool (3.0), while the Pendleton black also stained wool (3.5). Results of tensile strength (table 6) indicate the fabric was sufficiently durable (P black-30.6, P squash-55.0, ww blue-56.5) to serve as an outerwear jacket. The ultraviolet tests (table 7) indicate the fabrics were able to withstand the light (P black-4.75, P squash-4.75, ww blue-4.5) without fading making the fabrics suitable for an outerwear product. All the tests confirmed the choice of fabrics as suitable for the product's future use.

Lining Fabric Selection

For the lining, 100% polyester satin was chosen because it is a C2C technical nutrient. The polyester chosen was dyed with an unknown dye during manufacturing. Ideally in a mass production execution of C2CDADP the polyester would also be C2C certified. Because C2C certified polyester could not be obtained, the polyester currently available in the market was used to demonstrate the proof-of-concept. A benefit of choosing polyester as a technical nutrient is it can be up-cycled into polyester for a new use or it can be burned for energy at the end of its lifecycle regaining the energy used to produce it.

Thread Selection

In order to plan for disassembly the thread must be chosen for construction of the product that matches the nutrient type of the fabric being sewn. During the design of a sustainable product every element must be chosen responsibly to protect the C2C integrity of the product. For the wool shell, cotton thread was used because of its availability and ability to mix with wool. Ideally, all thread used should be a pure biological or technical nutrient. The polyester components use 100% polyester thread to maintain the purity of the polyester components. Eventually, the technical nutrient thread should be produced in a sustainable manner along with the fabric.

Methods of Disassembly

Possible methods for easy disassembly between the shell and lining were identified and evaluated for feasibility and compatibility with C2CDADP. Methods that would result in either the shell or lining not remaining pure were eliminated. Methods eliminated included zippers, snaps, and hook and loop tape. The most promising using currently available components were stitching and buttons. Instead of adhesive and stitched attachment of the lining to the shell with stitching; other options such as stitching and buttons to hold the two together were explored. The material assessment protocol flow chart helped assess the materials sustainability and disassembly potential, while the C2CAD model aided in the design and assessment of the apparel.

Complications in the use of stitching include: sewing the disassembleable components together requires the use of thread in the needle and the bobbin to be different nutrients. While one thread can be used in the needle to correspond with one fabric, the bobbin thread could correspond with be the other fabric however; unavoidably a small amount of thread mixing will happen. Another issue of using stitching was the potential confusion on the consumer's part as to how to disassemble the pieces. Without special instructions the consumer may disassemble the wrong components or fail to disassemble the garment at all. The stitching also prevents the consumers' ability to replace parts of the product easily on their own. These issues lead this project in the direction of utilizing buttons as a form of connecting the various components. The time required disassembling the garment using buttons as the connection between the shell and the lining was three minutes and twenty-eight seconds.

The connection of the shell and the lining used a simple yet innovative system of buttons. Buttons provide an affordable, sustainable option to connect the shell to the lining. Consumers are comfortable with the concept and use of buttons so no confusing instructions are needed to disassemble the garment. The connection was permanent for use during wear, but easy for any consumer to disassemble before the recycling of the product at the end of its useful life. Buttons can also allow for a consumer to replace a single aspect of a product if the one component wears out, such as a lining, but the rest of the product remains useable.

Buttons can be biological or technical nutrients depending on the needs of the design. Buttons can meet a functional aspect of design as well as an aesthetic need if the designer chooses to use them in that manner. All biological nutrient buttons must only be sewn with biological nutrient thread to biological nutrient fabrics while technical nutrient buttons (such as polyester) must only be sewn with thread of the exact same type nutrient as the fabric in order to preserve “purity”. The proof-of-concept jacket successfully maintained the ideals of design for disassembly. The shell and lining are easily unbuttoned to allow for the components to recycle (figure 2).

The buttons chosen for the proof-of-concept were Akoya shell buttons. The buttons are made from leftover shells from harvesting Akoya pearls making them biological nutrients. The shells are waste from the pearl harvesting process and utilized as raw material for buttons. The buttons are available in mass quantities in various shapes and sizes as an economic choice. The buttons are inexpensive in mass and since many buttons were used in the product they did not force the garment price point up. The buttons are also attractive and if used in a product where they are visible they have a decorative element as well. The buttons can also be covered to match fabric choice in products if that look is desired.

Design Development

The design and construction of the jacket utilized information and available resources imitating mass production (Shaeffer, 2001). The design of a men's jacket was used to implement design for disassembly as a proof-of-concept. The reason for selecting a man's jacket was that it was considered one of the most complicated apparel products to produce. The traditional men's jacket includes a shell, a lining, and a large amount of toxic adhesives and interfacings. While the initial goal was to construct a man's suit jacket the fabric choice led the design to evolve into a classic outerwear short overcoat type jacket. Due to the fabric being designed for use in interiors, it was thick and relatively casual looking. The traditional method of constructing a jacket includes permanent connections without consideration of disassembly and developing an alternative became the challenge. The process involved making a variety of prototypes learning the importance of inner support through stitching. The garment uses topstitching and under-stitching to create flat seams and a crisp overall shape to the jacket.

The collar and lining attachment around the neck of the garment presented a challenge. The resulting design displays the button attachment of the lining without a flap to cover them in order to eliminate the bulk of too many layers (figure 2). The need for enough layers to support and shape the jacket while eliminating bulk provided the need for balance (figure 2). The majority of buttons were covered with a flap to prevent the consumer from potentially catching on the buttons during use.

The jacket pattern once drafted was digitized and translated into GerberSuite CAD and use an automated cutting table in order to imitate the process of mass production. While the cutting table used was small in comparison to large manufacturers it provided the cutting service needed. All straight stitches were done on the industrial sewing machines. The lack of an industrial buttonhole machine was sorely missed as the design has a large number of buttonholes. If this garment were to be mass produced it would greatly benefit from the clean high speed button-hole machines making the construction of the jacket significantly simpler.

Design Evaluation

The jacket met the requirements outlined for the project. The jacket has a classic look designed to disassemble in order to allow for a sustainable product lifecycle. The shell can either become compost, or be ground up for reprocessing into a new product. The lining can be melted down and then remade into something new, or burned for energy.

Revising, and reevaluating the jacket as needed simultaneously existed with other aspects during the processes. Revised sewing techniques included adding under-stitching and topstitching to add support to the jacket. Because interfacings and glues had been eliminated, inner support of the jacket to create the shape was needed from other means such as stitching and buttons. Once the buttons were added, inner support and shape were provided. The buttons helped create a flexible, yet sturdy inner support system.

The costing of the garment was done using both the Pendleton C2C wool and the TestFabrics worsted wool in an effort to gain an idea of the cost of the garment to both a company and the consumer (table 9). Both fabrics were costed because the higher price of the C2C wool The higher cost was a result of the C2C wool being an interior fabric, as well as one the first C2C certified fabrics. The worsted wool gives a better idea of what the jacket would cost with an apparel fabric. The C2C wool jacket resulted in a retail cost of $182.44, while the retail cost of the worsted wool was $125.44 based off shipping and manufacturing costs from the Dominican Republic (WRC, 2005). Since apparel products are primarily manufactured outside of the U.S. basing the costs outside the U.S. as well seemed logical.

Additional design evaluation was received during the EPA P3 exposition and judging in April 2008 in Washington D.C. This project was displayed for judging as part of the exposition on sustainability solutions proposed and demonstrated by teams from various universities receiving an honorable mention award. Feedback from the team of six judges was positive and included notes on ease of customer use, and on the ease of direct application to the apparel industry and relevance to sustainability’s three prongs of people, planet and prosperity. Thus the evaluation of design included both internal and external review.

Discussion, Conclusions and Recommendations

Many apparel products contain several components making design for disassembly an important process to implement in the apparel production industry. In further study, additional options for sustainable design and design for disassembly in many other areas should be developed. Studying other methods of disassembly, the development of new sustainable interfacing, thread, and closures such as snaps and hooks would be highly beneficial to developing C2C sustainable products for the apparel industry. Better options for components would make the process of sustainable design significantly easier. The development of technical nutrient options that meet sustainability criteria could replace multi-nutrient components for effective recycling options.

Development of a sustainability evaluation and labeling system is highly recommended for apparel products. A labeling and regulation system to identify and verify the sustainability of products would alleviate greenwashing and encourage true sustainability within the industry.

Table 1: Test Protocol Summary

Mechanical Properties	Performance	Samples	Test Method	Equipment	Replicates
	Strength	Pendleton woolen fabric (Black and Squash) Worsted flannel (blue)	ASTM D 5035	Thawing-Albert EJA Universal Materials Testing Instrument	3
	Resistance to pilling	Pendleton woolen fabric (Black and Squash) Worsted flannel (blue)	ASTM D 3512	Atlas Random Tumble Peeling Tester	3
Color Fastness in Fabric	Accelerated Laundry fastness	Pendleton woolen fabric (Black and Squash) Worsted flannel (blue)	AATCC 61	Atlas Launderometer	3
	Sunlight fastness	Pendleton woolen fabric (Black and Squash) Worsted flannel (blue)	AATCC 16	Atlas Suntest XLS	3
	Crocking fastness	Pendleton woolen fabric (Black and Squash) Worsted flannel (blue)	AATCC 8	Atlas Crockmeter CM-5	3

Table 2: Dying Process Results for Worsted Wool

Fabric	Lanasol Dye	Amount of Dye	Salt	Boiling Water	Time
Worsted Wool	Blue	1.500 g	1.000 g	1500 ml	2 min
Worsted Wool	Yellow	1.000 g	1.000 g	1500 ml	2 min

Note: All dye and salt measurements at.000g accuracy

Table 3: MSDS Assessment of Huntsman Lanasol Dyes used for Dye Assessment

	Lanasol Blue and Lanasol Yellow
Acute toxicity LD50 oral	>5,000 mg/kg, rat
Primary irritation (skin)	Non-irritant, rabbit
Primary irritation (eye)	Non-irritant, rabbit
Skin sensitization	Sensitizer, Guinea pig
Adverse effects in man	No adverse effects reported

Table 4: Crocking Test for Wools

		Fabric Type	Mean
Crocking	Dry	Pendleton-Squash	4.75
		Pendleton-Black	4.00
		Worsted Wool- Blue	4.42
	Wet	Pendleton-Squash	4.25
		Pendleton-Black	3.00
		Worsted Wool-Blue	3.84

Table 5: Accelerated Laundry Test with Launderometer for Wools

		Fabric Type	Mean
Laundry Test	Color changing	Pendleton-Squash	4.75
		Pendleton-Black	4.75
		Worsted Wool-Blue	4.00
	Staining acetate	Pendleton-Squash	5.00
		Pendleton-Black	4.50
		Worsted Wool-Blue	5.00
	Staining cotton	Pendleton-Squash	4.75
		Pendleton-Black	4.75
		Worsted Wool-Blue	2.25
	Staining nylon	Pendleton-Squash	3.25
		Pendleton-Black	4.50
		Worsted Wool-Blue	4.75
	Staining polyester	Pendleton-Squash	5.00
		Pendleton-Black	5.00
		Worsted Wool-Blue	5.00
	Staining acrylic	Pendleton-Squash	4.75
		Pendleton-Black	5.00
		Worsted Wool-Blue	4.50
	Staining wool	Pendleton-Squash	3.00
		Pendleton-Black	3.50
		Worsted Wool-Blue	3.00

Table 6: Strength Test for Wools

		Fabric Type	Mean
Strength Test	Strength (lbs)	Pendleton-Black	30.60
		Pendleton-Squash	55.00
		Worsted Wool-Blue	56.50
	Elongation(Inches)	Pendleton-Black	0.967
		Pendleton-Squash	1.296
		Worsted Wool-Blue	0.828

Table 7: Sunlight Test for Wools

		Fabric Type	Mean
Sunlight Test	Color Changing	Pendleton-Squash	4.75
		Pendleton-Black	4.75
		Worsted Wool-Blue	4.50

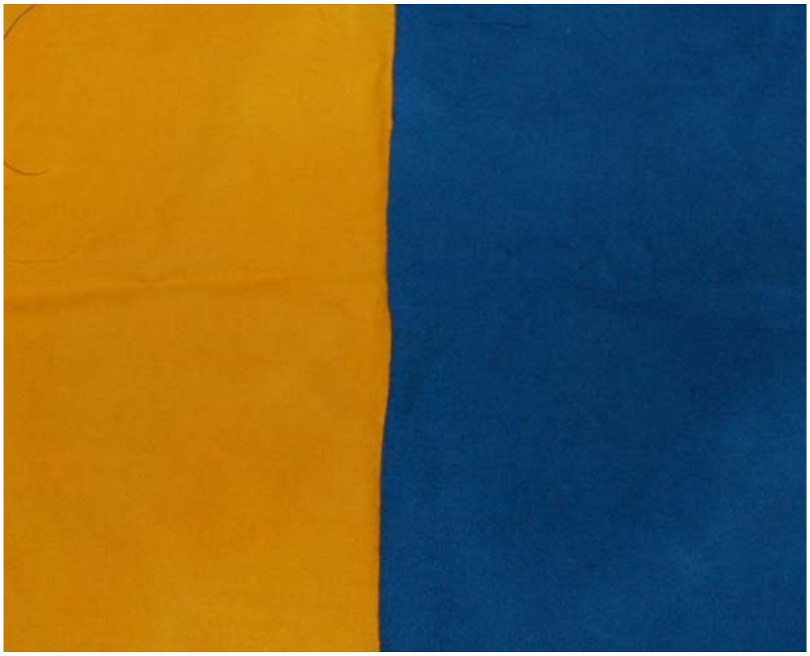
Table 8: Resistance to Pilling for Wools

	Fabric Type	Mean
Resistance to Pilling	Pendleton-Squash	3.00
	Pendleton-Black	3.08
	Worsted Wool- Blue	3.83

Table 9: Costing Estimate

Cost Estimates for Jacket						
(use wholesale cost estimate to generate cost of jacket since mass production obtains items cheaper than individual)						
Formula	**Non Labor Costs**		**Cost**	**Used**	**Cost of Used-Pendleton**	**Cost of Used-Worsted Wool**
	Fabric	Pendleton Wool	Retail= $29.00/yd Wholesale= $14.50/yd	2.5	$36.25	
		Worsted Wool	Retail= $17.60 Wholesale= $8.80			$22.00
		Polyester	Retail =$3.99/yd Wholesale= $2.00/yd	2	$4.00	$4.00
	Buttons (Akoya Shell)	1/2"	Retail=144/ $12.00 Wholesale $6.00	60	$2.50	$2.50
		1"	Retail=144/ $20.64 Wholesale= $10.32	5	$0.36	$0.36
	Thread	Cotton	Retail=$1.99/ 375 yds Wholesale= $1.00	?	$0.25	$0.25
		Polyester	Retail= $3.19/3,000 yds Wholesale= $1.59	?	$0.25	$0.25
a	**Total Non Labor Costs**				*$43.61*	*$29.36*
b	**Labor Cost of Production** (includes direct and supervisory labor)		0.45		$0.45	$0.45
c (a+b=c)	**FOB Price** (price to brand at factory door: includes all labor and non-labor production costs)				$44.06	$29.81
c+d= e	**Land-Duty-Paid (LDP) Price** (final cost to brand; includes FOB price + (shipping, duty, delivery, insurance, and customs clearance=d)				$45.61	$31.36
2*e=f	**Wholesale Price** (add salary of designers and company running expenses and profit)				$91.22	$62.72
2*f=g	**Retail Price** (covers costs of running store and profit)				$182.44	$125.44

Figure 1: Dye Color Samples for Worsted Wool



Note: Squash (Left), Blue (Right)

Figure 2: Garment Details

Front

Collar

Shoulder and Topstitch Detail

Back and Back Yoke

Connection to Lining

Covered Button

Figure 3: Jacket Shell

Front: Top, Back: Bottom

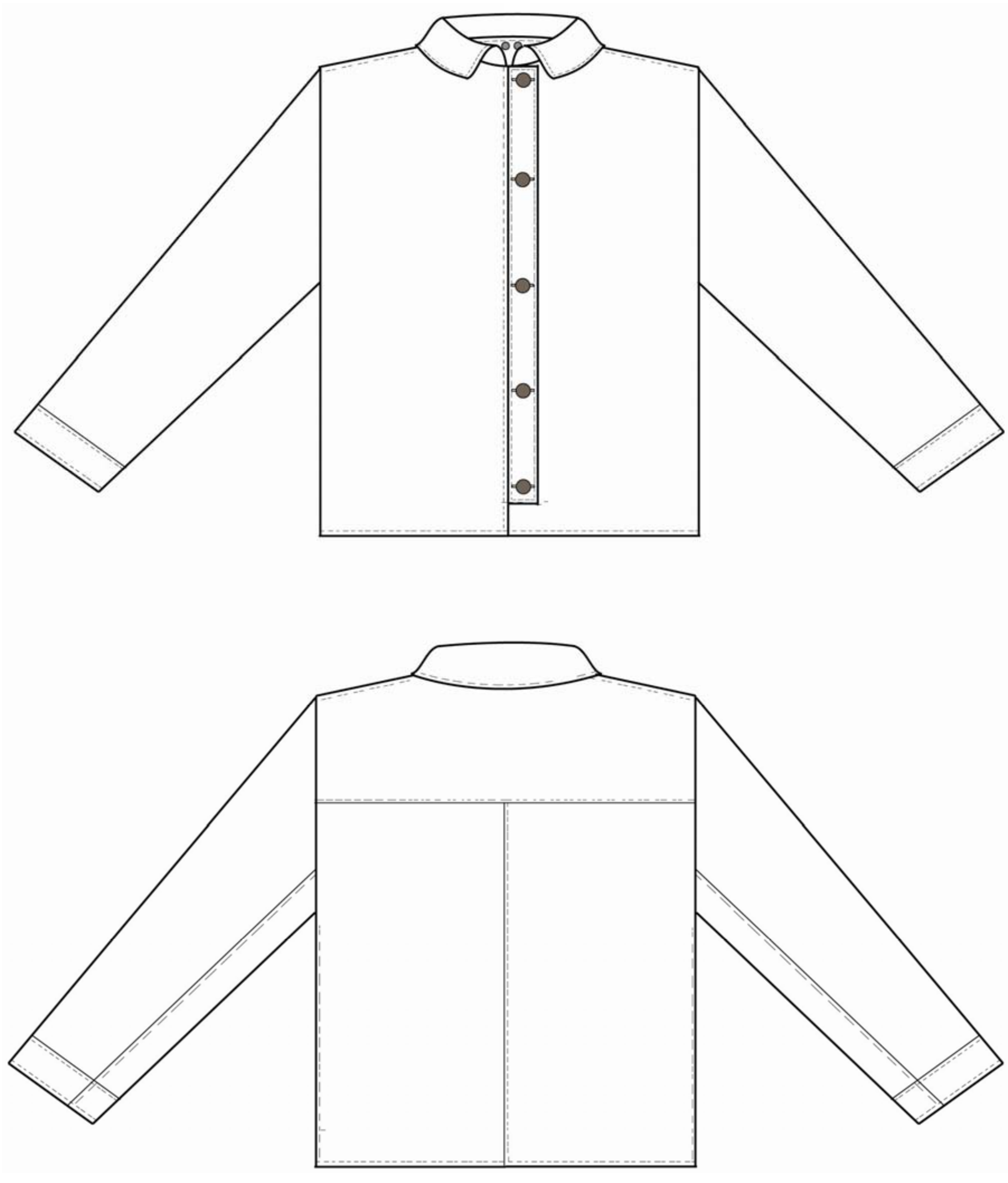
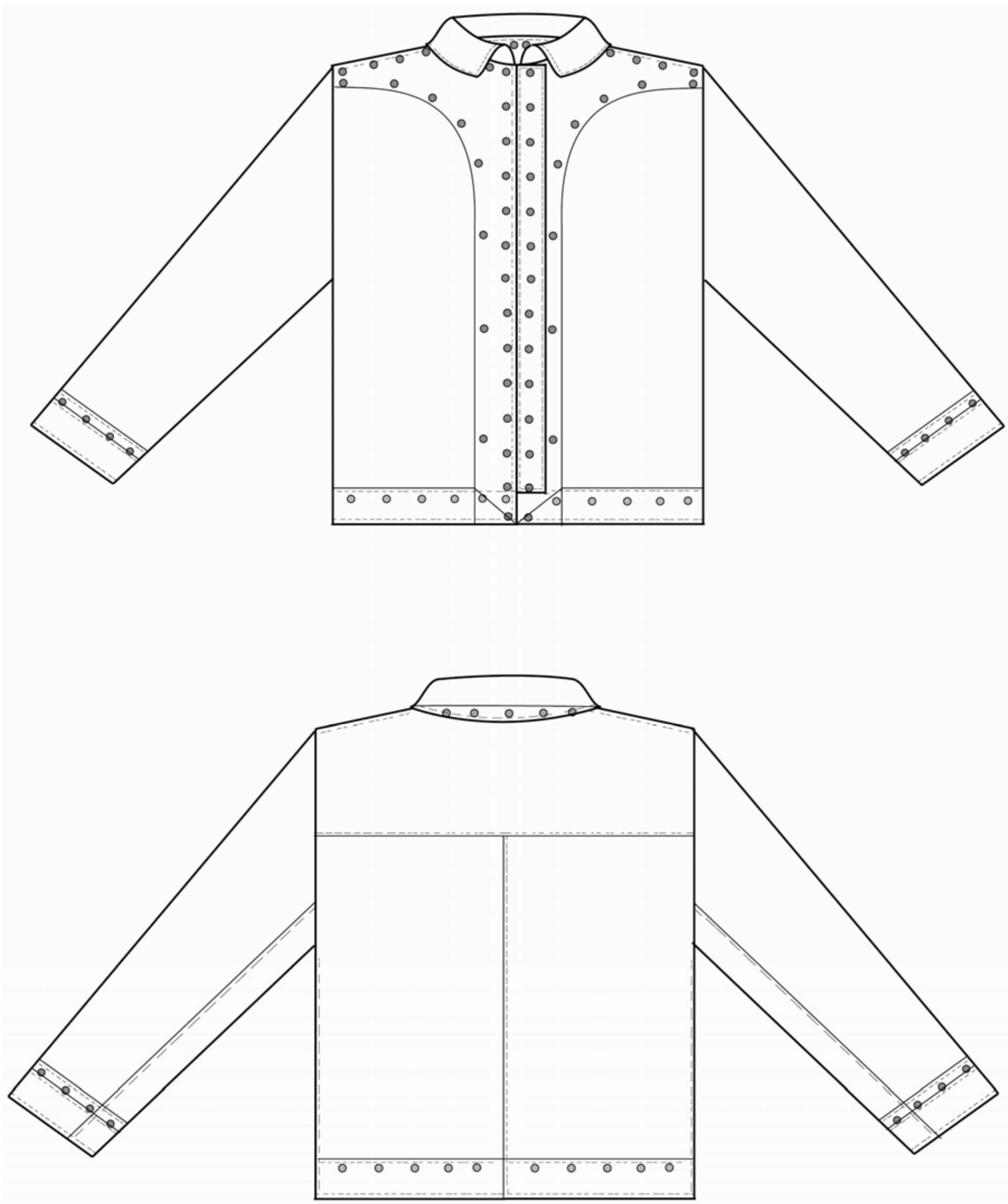


Figure 4: Jacket with x-ray view of interior components (buttons) on the shell connecting the lining to the shell; Lining has corresponding buttonholes for easy connection



REFERENCES CITED

American Association of Textile Chemists and Colorists AATCC (2004), AATCC Technical Manual, American Association of Textile Chemists and Colorists, North Carolina.

American Sheep Industry Associates (ASI). (December 14, 2007). Weekly Newsletter. Retrieved December 1, 2008 from www.sheepusa.org

American Society for Testing and Materials ASTM (2004), Annual Book of ASTM Standards, Vol 07, American Society for Testing and Materials, Philadelphia.

Atmosphere, Climate & Environment Information Programme. (2002) Sustainable Development. Retrieved July 22, 2008 from http://www.ace.mmu.ac.uk/Resources/Teaching_Packs/Key_Stage_4/Sustainable_Development/03a.html

Axelrod, J, & Fram, E.H.. (1990), "The distressed shopper", *American Demographics*, Vol. 12 pp.44-5.

Bioaccumulation. (n.d.). *Dictionary.com Unabridged (v 1.1)*. Retrieved November 14, 2007, from Dictionary.com website: http://dictionary.reference.com/browse/bioaccumulation

Cotte J &. Trudel ,R., (May 12, 2008). Business Insight (A Special Report): Corporate Reputation; Does Being Ethical Pay? Companies spend huge amounts of money to be 'socially responsible;' Do consumers reward them for it? And how much?. NY: Wall Street Journal. (Eastern Edition) p. R.4

Franklin Associates, LTD. (1993). Resource and Environmental Profile Analysis of a Manufactured Apparel Product, Life Cycle Analysis (LCA): Woman's Knit Polyester Blouse [Electronic Version]. *American Fiber Manufacturers Association, 1-10.* Retrieved June 19, 2008 from WorldCat (Worldwide Library Collections)

Gam, Hae Jin (2007) Development and Implementation of a Sustainable Apparel Design and Production Model. Ph.D. dissertation, Oklahoma State University, United States -- Oklahoma. Retrieved June 13, 2008, from Dissertations & Theses at Oklahoma State University - Stillwater database. (Publication No. AAT 3259611).

Herman Miller, Mirra and Celle Chair Photos and Information, Retrieved from http://www.hermanmiller.com/ June 24, 2008.

Ho, C. (July, 2003). Eco Fraud. *Architecture*, *92*(7), 31. Retrieved July 22, 2008, from Academic Search Elite database

Kadolph, S. J. (2007). Textiles. (10th ed.) Upper Saddle River, NJ: Merrill/Prentice Hall

M2 Presswire (December 28, 2005). UK Government: Consumers Urged to get grips with green labels. Coventry, p1

McDonough, W, & Braungart, M. (2002). *Remaking the way we make things: Cradle To Cradle.* NY: North Point Press.

National Cotton Council of America. (2005, March). *U.S. Cotton Economic Situation and Issues Update.* Retrieved September 15, 2007, from http://www.cotton.org/issues/2005/upload/econoutlookissues.pdf

Pendleton Woolen Mills. (2008). Cradle to Cradle Certified Fabric Swatch Card. Received Fall 2007 from Pendleton

The Sustainability Report. (2004). Homepage. Retrieved July 22, 2008 from http://www.sustreport.org/

TestFabrics Inc. (2008). Worsted Wool for Dying. Retrieved December 2007 from http://www.testfabrics.com/

Shaeffer, Claire . (2001). Sewing for the Apparel Industry. NJ: Prentice Hall

U.S. Census Bureau. (2004, March 18). *Projected Population of the United States, by Race and Hispanic Origin: 2000 to 2050.* Retrieved Nov 10, 2007 from http://www.census.gov/ipc/www/usinterimproj/natprojtab01a.pdf

United States Environmental Protection Agency. (2006, July 31). *Finalization of Interim Reregistration Eligibility Decisions (IREDs) and Interim Tolerance Reassessment and Risk Management Decisions (TREDs) for the Organophosphate Pesticides, and Completion of the Tolerance Reassessment and Reregistration Eligibility Process for the Organophosphate Pesticides.* Retrieved December 4, 2006 from http://www.epa.gov/oppsrrd1/REDs/acephate_ired.pdf

United States Department of Agriculture: National Agricultural Statistics Service (USDA NASS). (October 2004). *Agricultural Chemical Usage 2003 Restricted Use Summary*. Retrieved December 4, 2006, from the http://usda.mannlib.cornell.edu

Worker Rights Consortium (WRC). (November 2005). *The Impact of Substantial Labor Cost Increases on Apparel Retail Prices.* Retrieved November 26, 2008 from the www.workersrights.org

CHAPTER V

CONCLUSION

Many complex apparel products make design for disassembly an important process to implement in the apparel industry. In this example, the result of the process was a men's jacket, however, the process will work with any apparel product. In further examination of the subject of sustainable design and design for disassembly many other areas can be studied. Studying other methods of disassembly, the development of new sustainable interfacing, thread, and closures such as snaps and hooks would be highly beneficial to the apparel industry. Both biological and technical nutrient items need further development. The development of options that meet sustainability criteria would be able to help replace current harmful options used. Better options for components would make the process of sustainable apparel design much easier.

The next step in design for disassembly should also include a larger scale production of a product to demonstrate the principles and transfer them from a proof-of–concept to a mass production reality. Producing any complex garment with multiple components would help lead the apparel industry forward in designing and producing both sustainable products and products designed for disassembly.

Another aspect of sustainability for the apparel industry to consider is greenwashing. By designing a system of labeling and verification of sustainability, apparel products would be able to accurately represent their impact on the environment and consumer. Perhaps a color coding based on adherence to sustainability guidelines in logo form, possibly on a hang tag, could be added to products. The system could be based upon LEED used in Green Building Certification. This system would alleviate customer confusion when shopping and reward the companies that produce truly sustainable products with a label proving their adherence to guidelines. Possibly in the initial years of sustainable apparel product tax deductions could be used as incentives or preferential shelf/store placement can be offered in shopping establishments.

A poster of the project and the garment were presented at the EPA P3 expo competition in Washington D.C. April 20-22, 2008. An honorable mention was given based on the research done (Appendix 4). In educational efforts the basic concept of C2C apparel design and design for disassembly was presented at two workshops for high school students at a “Cloud Initiative” workshop. The information was presented in both poster and presentation form at the 2008 ITAA conference.

REFERENCES CITED

American Association of Textile Chemists and Colorists AATCC (2004), AATCC Technical Manual, American Association of Textile Chemists and Colorists, North Carolina.

American Sheep Industry Associates (ASI). (December 14, 2007). Weekly Newsletter. Retrieved December 1, 2008 from www.sheepusa.org

American Society for Testing and Materials ASTM (2004), Annual Book of ASTM Standards, Vol 07, American Society for Testing and Materials, Philadelphia.

Atmosphere, Climate & Environment Information Programme. What is Sustainable Development?. Retrieved July 22, 2008 from http://www.ace.mmu.ac.uk/Resources/Teaching_Packs/Key_Stage_4/Sustainable_Development/03a.html

Axelrod, J, & Fram, E.H.. (1990), "The distressed shopper", *American Demographics*, Vol. 12 pp.44-5.

Bioaccumulation. (n.d.). *Dictionary.com Unabridged (v 1.1)*. Retrieved November 14, 2007, from Dictionary.com website: http://dictionary.reference.com/browse/bioaccumulation

Chang, Y. Chen, H-L., Francis, S. (1999) Market Applications for Recycled Postconsumer Fibers. Family and consumer Sciences Research Journal. 27.320. retrieved August 26, 2008 from fcs.sagepub.com

Cotte J &. Trudel ,R., (May 12, 2008). Business Insight (A Special Report): Corporate Reputation; Does Being Ethical Pay? Companies spend huge amounts of money to be 'socially responsible;' Do consumers reward them for it? And how much?. NY: Wall Street Journal. (Eastern Edition) p. R.4

Climatex.(1997). Fabric Information and Data. Retrieved November 11, 2008 from http://www.climatex.com/en/products/products_overview.php5

Council for Textile Recycling. (1998, March 2). Don't Overlook Textiles. Retrieved Aug 22, 2008 from www.textilerecycle.org

DesignTex A Steelcase Company. (2008). Environmental Design. Retrieved June 24, 2008 from http://www.dtex.com

Environmental Working Group (EWG) (2003). *Mount Sinai School of Medicine Research on Human Exposure to Environmental Chemical*. Retrieved December 4, 2006 from http://www.ewg.org/

Franklin Associates, LTD. (1993). Resource and Environmental Profile Analysis of a Manufactured Apparel Product, Life Cycle Analysis (LCA): Woman's Knit Polyester Blouse [Electronic Version]. *American Fiber Manufacturers Association, 1-10.* Retrieved June 19, 2008 from WorldCat (Worldwide Library Collections)

Gam, Hae Jin (2007) Development and Implementation of a Sustainable Apparel Design and Production Model. Ph.D. dissertation, Oklahoma State University, United States -- Oklahoma. Retrieved June 13, 2008, from Dissertations & Theses at Oklahoma State University - Stillwater database. (Publication No. AAT 3259611).

Harvey, John. (March 2000). New Restrictions on Wool Production. Pesticides News, No. 47, Retrieved December 1, 2008 from http://www.panuk.org/pestnews/Issue/pn47/pn47p15.htm

Herman Miller, Mirra and Celle Chair Photos and Information, Retrieved from http://www.hermanmiller.com/ June 24, 2008.

Ho, C. (July, 2003). Eco Fraud. *Architecture*, *92*(7), 31. Retrieved July 22, 2008, from Academic Search Elite database

Kadolph, S. J. (2007). Textiles. (10th ed.) Upper Saddle River, NJ: Merrill/Prentice Hall

M2 Presswire (December 28, 2005). UK Government: Consumers Urged to get grips with green labels. Coventry, p1

McDonough, W, & Braungart, M. (2002). *Remaking the way we make things: Cradle To Cradle.* NY: North Point Press.

National Cotton Council of America. (2005, March). *U.S. Cotton Economic Situation and Issues Update.* Retrieved September 15, 2007, from http://www.cotton.org/issues/2005/upload/econoutlookissues.pdf

Organic Trade Association (OTA). (2008).Wool and the Environment. Retrieved December 1, 2008 from http://www.ota.com/wool_environment.html

Pendleton Woolen Mills. (2008). Cradle to Cradle Certified Fabric Swatch Card. Received Fall 2007 from Pendleton

Prasad, G V. Dr. Reddy's Laboratories Ecoefficiency vs. Ecoeffectiveness. Retrieved July 22, 2008 from http://greenbusinesscentre.com/documents/eco.pdf

Shaeffer, Claire . (2001). Sewing for the Apparel Industry. NJ: Prentice Hall

The Sustainability Report. (2004). Homepage. Retrieved July 22, 2008 from http://www.sustreport.org/

Tematex by True Textiles.(2008). Fabric Information. Retrieved November 11, 2008 from http://www.truetextiles.com/

TestFabrics Inc. (2008). Worsted Wool for Dying. Retrieved December 2007 from http://www.testfabrics.com/

U.S. Census Bureau. (2004, March 18). *Projected Population of the United States, by Race and Hispanic Origin: 2000 to 2050.* Retrieved Nov 10, 2007 from http://www.census.gov/ipc/www/usinterimproj/natprojtab01a.pdf

United States Environmental Protection Agency. (2006, July 31). *Finalization of Interim Reregistration Eligibility Decisions (IREDs) and Interim Tolerance Reassessment and Risk Management Decisions (TREDs) for the Organophosphate Pesticides, and Completion of the Tolerance Reassessment and Reregistration Eligibility Process for the Organophosphate Pesticides.* Retrieved December 4, 2006 from http://www.epa.gov/oppsrrd1/REDs/acephate_ired.pdf

United States Department of Agriculture: National Agricultural Statistics Service (USDA NASS). (October 2004). *Agricultural Chemical Usage 2003 Restricted Use Summary*. Retrieved December 4, 2006, from the http://usda.mannlib.cornell.edu

Wordnet.(2008). Definition of Organic, and Toxic. Retrieved August 28, 2008 from http://wordnet.princeton.edu/perl/webwn?s=organic

Worker Rights Consortium. (November 2005). *The Impact of Substantial Labor Cost Increases on Apparel Retail Prices.* Retrieved November 26, 2008 from the www.workersrights.org

APPENDICES

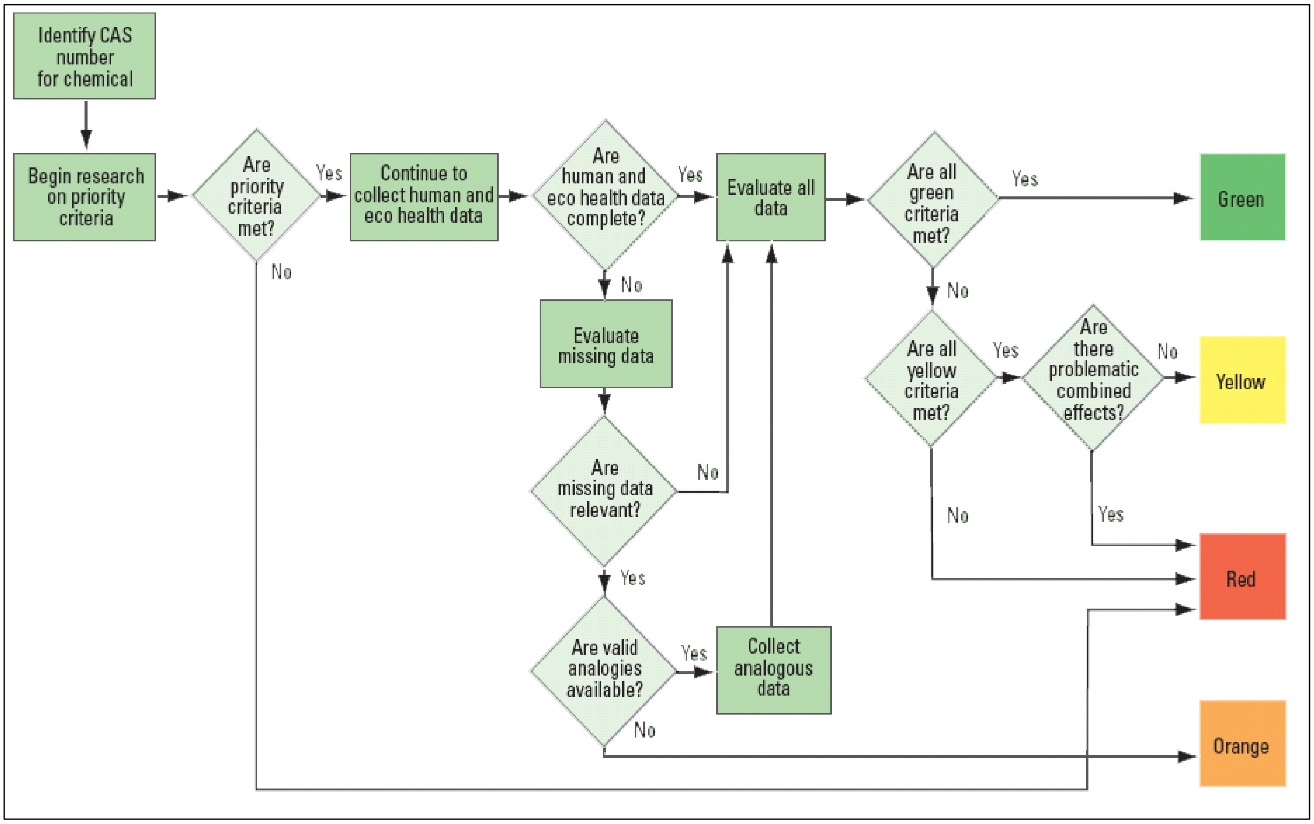
Appendix 1: Herman Miller Chairs

1.1 Mirra Chair

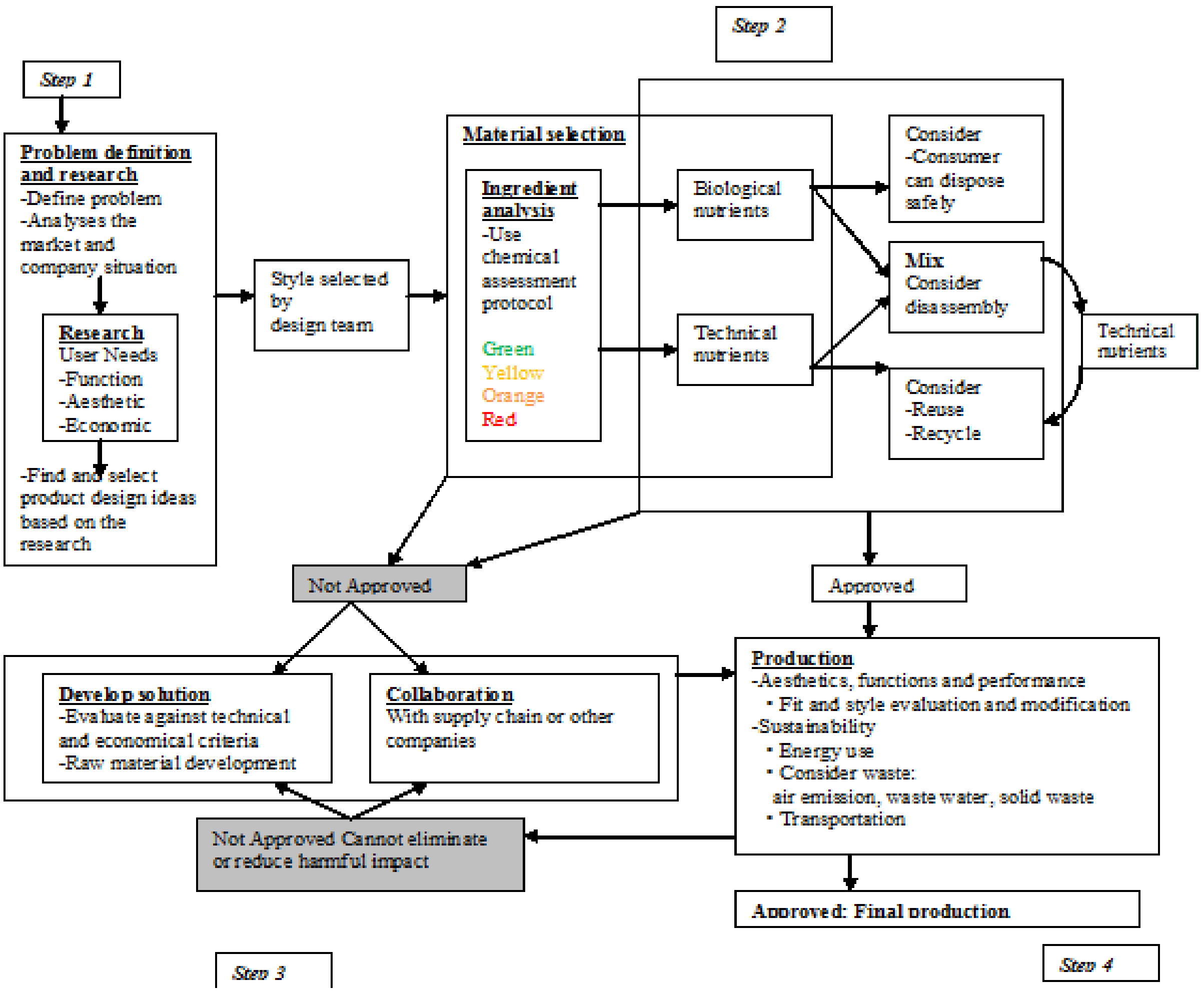
Left: Assembled Mirra Chair, Center: Recyclable components of disassembled chair, Right: Non-recycleable components of disassembled

1.2 Celle Chair

Appendix 2: Material assessment protocol (McDonough, et al., 2003)



Appendix 3: C2C Conceptual Framework for Apparel Design and Production (Gam H, 2007)



Appendix 4: EPA P3 Honorable Mention Certificate

People, Prosperity and the Planet

Honorable Mention

The U.S. Environmental Protection Agency
Hereby Recognizes

Jaclyn Bennett, Caroline Helmkamp, Rachel Rumsey,
Huantian Cao, Cheryl Ann Farr, and Hae Jin Gam
Oklahoma State University and
Illinois State University

For the Quality of their Design and Proposal for
the Environmental Protection Agency's
2008 P^3 Program — People, Prosperity and the Planet

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

George M. Gray
Assistant Administrator for
Research and Development

VITA

Rachel Rumsey

Candidate for the Degree of

Master of Science

Thesis: DESIGN FOR DISASSEMBLY: AN IMPLAMENTATION OF C2CAD

Major Field: Human Environmental Sciences
Area of Specialization: Design, Housing and Merchandising
Concentration: Apparel Design and Production

Biographical:

Education:

Oklahoma State University 2006

B.S. Design, Housing and Merchandising with Option in Apparel Design and Production

Will complete the requirements for the Master of Science in Design, Housing and Merchandising with option in Apparel Design and Production at Oklahoma State University, Stillwater, Oklahoma in May, 2009

Experience:

- Adjunct Instructor in Design, Housing and Merchandising Department at Oklahoma State Fall 2008-Present
- Instructor in Design, Housing and Merchandising Department at Oklahoma State University 2007-2008
- Design Team Member of the Institute of Protective Apparel and Research and Technology (IPART) 2006-2008
- Research Assistant in Design, Housing and Merchandising Department at Oklahoma State University 2006-2008
- Teaching Assistant in Design, Housing and Merchandising Department at Oklahoma State University 2006-2008
- Design Center Intern at May Merchandising Company, Summer 2005
- Residential Advisor at Oklahoma State University, 2003-2005
- Design Intern at Tiffany Alana Summer, 2004
- Wardrobe Production Assistant at STAGES, 2002, 2003
- Art Intern at the Contemporary Museum of Art in St. Louis, 2000-2002

Name: Rachel Rumsey Date of Degree: May, 2009

Institution: Oklahoma State University Location: Stillwater, OK

Title of Study: DESIGN OF DISASSEMBLY: AN IMPLEMENTATION OF CRADLE TO CRADLE APPAREL DESIGN (C2CAD)

Pages in Study: 66 Candidate for the Degree of Master of Science

Major Field: Design, Housing and Merchandising, Apparel Design and Production

Scope and Method of Study: Sustainability issues as related to the apparel industry are a relevant aspect of impact to consider. The repercussions of the apparel industry's actions are huge and have the potential to change into a responsible industry. The guidelines from McDonough and Braungart's "Cradle to Cradle" theory provides the path to sustainability. Although seemingly eco-friendly products are seen in the apparel market, the sustainability of these items must be seriously questioned. After initial market examination of complex apparel products currently available this designer noted the lack of true eco-effective apparel. Thus, the purpose is to develop a prototype disassemble-able man's jacket that can be an example of an eco-effective, complex garment that can be compatible with C2C concept of recycling.

The objectives of this research are to: 1) Source and test components for sustainable apparel including, fabric: interfacing, thread, seams, stitches, closures, dyes and design for sustainability. 2) Evaluate and select appropriate components and combinations of components to construct a men's jacket as an example of sustainable disassembleable apparel product. 3) Design and construct a jacket adaptable to mass production. 4) Evaluate the performance, cost, and overall results of the jacket. 5) Revise and reevaluate jacket as needed. 6) Exhibit jacket, related design features, and textile test results.

Findings and Conclusions: The prototype of a man's jacket was developed using the Cradle to Cradle theory utilizing both biological and technical nutrients in an effort to best demonstrate the design for disassembly process. The jacket separates utilizing buttons as a simple, cost effective option for disassembly. The jacket imitated mass production methods to ease the transition of the Cradle to Cradle concept into the industry. The test results were favorable and recommendations on continuing sustainability issue research were discussed.

ADVISER'S APPROVAL: Dr. Cheryl Farr